A Quantified Fire Risk DESIGN METHOD

By *Fredrik Nystedt*

The term fire risk analysis incorporates a variety of different methods. These methods are not unique for fire safety and could therefore be divided into the following well-established categories of risk analysis methods, namely qualitative, semiquantitative, and quantitative methods.[1]

OVERVIEW OF RISK ANALYSIS METHODS

Qualitative methods are often used in an informal way when a well-defined trade-off is evaluated and the effect on the fire safety strategy is limited. Designer experience and engineering judgment are often sufficient to make minor alternations to existing accepted solutions or to rank performance of different safety measures qualitatively. The performance criterion used in the verification is relative and can be expressed as “as safe as” or “not worse than.” The use of semiquantitative methods have only recently begun in the design process of buildings. In industrial risk management, methods like the balanced scorecard and index methods have been widely used to rank and prioritize different preventive safety measures. In Sweden, similar methods are developed for healthcare facilities as a tool to use for fire service inspection.[2] In the context of fire safety design, risk analysis is used to verify that threshold levels of risk are not exceeded for a design solution. The method of verification is based on a comparison of derived risk with some form of design criterion.

THE FIRE SAFETY DESIGN PROCESS

In Sweden, there are two code compliance methods available: the prescriptive, or “deemed-to-satisfy,” method and a performance-based design method. The performance-based design method uses an engineering methodology to approach the design problem. An engineering solution is developed and analyzed to determine whether it achieves the fire safety objectives. The keyword is to “verify” that a satisfactory level of safety is achieved. Risk-based methods may be used for this analysis. Figure 1 outlines the design process.

CASE STUDY IN QUANTIFYING FIRE RISKS

A case study was performed on a fictive hospital building in Sweden in 1998.[4] The aim of the case study was to quantify fire risks for a number of trial design solutions when building new hospitals. The analysis applied the QRA-methodology presented in this article. The approach presented in this section has been developed by the Department of Fire Safety Engineering at Lund University and is internationally presented in a number of journals and conferences.[5, 6, 7]

THE QUALITATIVE DESIGN REVIEW

The building consists of three stories and a basement. There is a daytime medical reception, a pharmacy, waiting hall, and a cafeteria on the entrance floor. The first and second floors consist of two hospital wards each. The two wards are separate fire compartments, and there is a protected lobby. The number of staff varies with the time of day. During the daytime, there are seven nurses available on each ward, and at night, there are only three. The

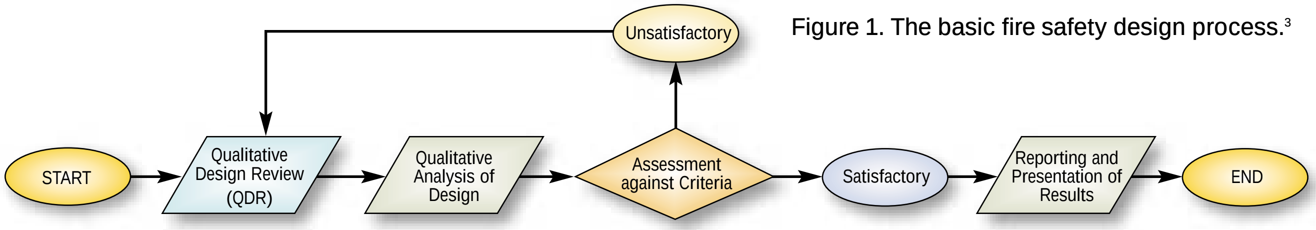

Figure 1. The basic fire safety design process.[3]

staff is trained in fire safety practices. There is a maximum of 36 patients on each ward which would need assistance to evacuate. Patients are assumed to be sleeping at night and to be awake during the day. The patients are not familiar with the building.

The objectives of the fire safety design are to limit the likelihood of fire, ensure safe evacuation of occupants, prevent large property losses, and protect the environment. In this study, only the first two objectives have been analyzed. Organizational fire safety is the key factor in fire prevention. Regular fire safety inspections and the staff training are two other elements in fulfilling this objective. Fire safety design solutions must ensure that the total escape time is shorter than the available safe egress time. A risk-based fire engineering method will be used to analyze this objective.

The evacuation strategy proposed is to move people from the ward where the fire is located to safe places, e.g., another ward or the protected lobby. Horizontal evacuation is the key tactic. However, if the escape route to the protected lobby is blocked, patients would be evacuated via the stairwell located at the end of each corridor. Evacuation to safe places must be carried out without the assistance of the fire service. If it is necessary, people can continue to perform total evacuation to the outside. For the design to be considered acceptable, occupants must, in the worst case, complete total evacuation approximately thirty minutes after the fire breaks out.

According to the Swedish regulations,[8] satisfactory escape shall be affected in the event of fire. The regulation gives some general recommendations on which design criteria are to be used in the analysis. These criteria provide limit states for visibility, temperature, and thermal radiation.

The fire hazards in hospitals include arson, technical malfunction, and forgotten stove. Fire by arson may occur in storerooms, nursing rooms, stairwells, etc. Technical malfunction includes fire in medical devices, televisions, etc. Kitchen devices, such as a hot plate or a forgotten stove, coffee machine, etc., may also result in a fire. Malfunctioning fluorescent tubes are also potential sources of ignition. Based on data from previous hospital fires, most fires start in the wards. The fire scenarios considered are:

- Arson in a nursing room involving a wastebasket, linens, or curtains
- Ignition in medical equipment in a nursing room
- Ignition caused by malfunctioning fluorescent tubes in a storeroom
- Fire in a coffee machine or the electric stove in the staff room
- Fire in the television set in the day room
- Unauthorized smoking in nursing rooms
- Fire in the cafeteria kitchen
- Arson in stairwells, basement, or garbage rooms
- Electrical failure, causing a fire in a shaft

Naturally, other scenarios beyond those listed above could occur. Expert judgment was used to determine which scenarios would be analyzed quantitatively: the nursing room fire caused by smoking in bed, the staff room fire caused by electrical failure in a coffee machine, and the cafeteria fire caused by fire in the deep-fryer.

Three trial design solutions were evaluated in the analysis:

- The first fire safety design solution (FSD1) is the reference solution in the comparative analysis and consists of smoke detectors placed throughout the ward and an alarm bell to notify occupants of fire.
- The second fire safety design solution (FSD2) consists of sprinklers and smoke detectors placed throughout the ward.
- The third fire safety design solution (FSD3) uses smoke and fire separating doors in the corridors, smoke detectors placed throughout the ward, and an alarm system that also notifies staff on adjacent wards so that they can assist in evacuation.

THE QUANTITATIVE RISK ANALYSIS

The event tree consists of a number of events (questions) where two answers are possible, “Yes” or “No”. The questions are put so that the answer “Yes” results in a better outcome, that is, lessening the consequences. A positive answer thus leads to longer available safe egress time or shorter evacuation time. A large number of scenarios are derived from the event trees.

The following events were included in the event trees:

Initial fire?
Daytime fire?
Nonflaming fire?
Fire suppressed by staff?
Automatic detection?
Door to room closed?
Staff response correct?
All escape routes accessible?
Door closed after fire?
Fire separation sufficient?
Sprinkler successful?
Staff back up available?
Fire & smoke separation successful?

The computerized two-zone model FAST[9] has been used to calculate the time elapsed before critical conditions are reached. The use of FAST does, however, require some precaution. The model is not valid after sprinkler activation. This problem is addressed by assuming that when the sprinkler activates before untenable conditions have been reached, the environment will not become life threatening.[10] In the hospital, the environment is considered to become untenable when the interface reaches a height of 1.9 m above the floor.

The evacuation phase consists of three steps that are assumed to be independent. These are detection, reaction, and travel. Detection time is calculated by using the computerized model Detact-T2.[11] The reaction time is estimated by using reference literature and depends on time of day and fire location. The travel time is calculated by a simple formula where the ratio between patients and members of staff is a key parameter.

RESULTS AND DISCUSSION

The risk due to fire is calculated for each fire safety design solution. The risk is quantified by calculating the safety margin, i.e., time to reach untenable conditions minus the total evacuation time for each of the scenarios in the event tree, and comparing it to the frequency at which the scenario could be expected. In order to create the risk profiles illustrated in Figure 2, the probability and consequence pairs for each

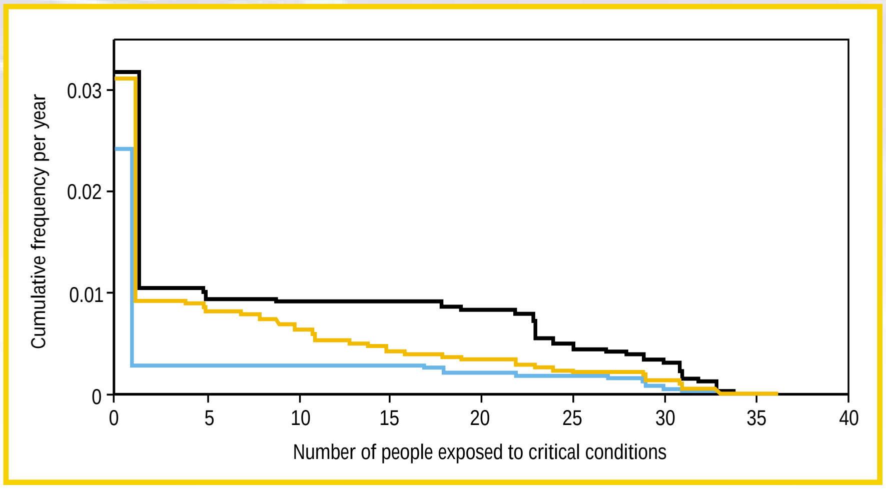

Figure 2. Risk profiles for the three fire safety designs. The upper (black) line represents FSD1, the middle (orange) line is for FSD3, and the lower (blue) line is for FSD2.

Table 1. Risk Measures for the Three Fire Safety Design Solutions

Design solution	Individual risk	Mean risk	Maximal consequence
FSD1	0.033	0.27	36
FSD2	0.024	0.09	36
FSD3	0.032	0.18	36

scenario must be graphed. When the pairs are graphed, it is possible to calculate the cumulative probability for a certain consequence and plot the result as a step function.

The risk profile provides the analyst with at least four important measures of the actual safety level. The first measure is the individual risk, i.e., the sum of the probabilities for all scenarios where the consequence is one or more deaths. This measure is the point on the Y-axis where the curve starts. The second measure is the mean risk. The mean risk is a measure of the risk to the society, stating what expected consequence a fire should have on average. The third measure is the slope of the curve. The higher slope the more risk averse is the design. A high slope is a fundamental risk evaluation criterion. The fourth measure is the maximal consequence, i.e., the value on the X-axis when the cumulative frequency is zero. The maximal consequence provides information on the worst possible outcome of a fire. The risk measures for the three fire safety designs are outlined in Table 1.

The risk profile for FSD1 illustrates that there is a relatively high risk for serious consequences, i.e., more than 20 people exposed to critical conditions. The evacuation of patients is highly dependent on the ratio between the number of patients and staff available to assist in evacuation.

The installation of sprinklers provides effective protection against untenable smoke and fire spread. The mean risk is lowered by 67% in FSD2 compared with the standard design. However, even when sprinklers are installed, there is a high-consequence, low-probability tail which cannot be reduced without decreasing the patient-to-staff ratio.

Using smoke-separating doors to limit smoke spread combined with a backup alarm system lowers the risk by about 33%. For between one and ten people, the profile corresponds well with the profile for the standard design (FSD1), but for ten or more exposed people, the profile agrees with the sprinkler risk profile.

The most cost-efficient way to reduce the risk of people being exposed to fire is therefore to install an alarm system that alerts members of staff on adjacent wards so that they can assist in the evacuation process in combination with the installation of smoke-separating doors in the ward.

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